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CONTRIBUTION OF ABDOMINAL MUSCLE ENDURANCE AND LEG MUSCLE STRENGTH TO JUMP HEIGHT IN EXTRACURRICULAR VOLLEYBALL

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Abstract
This study aims to determine the contribution of abdominal muscle endurance and leg muscle strength to jump height in volleyball extracurricular in Senior High School (SMA) in Palembang. The method used in this study is a quantitative correlational method, involving 30 male and female volleyball athletes selected through purposive sampling. Abdominal muscle endurance was measured using a one-minute sit-up test, leg muscle strength was measured with a vertical jump and quadriceps dynamometer, while jump height was measured using a jump reach test commonly used in the performance assessment of volleyball athletes. Data were analyzed using multiple linear regression analysis to determine the simultaneous and partial contribution of independent variables to dependent variables. The results showed that abdominal muscle endurance and leg muscle strength together contributed significantly to jump height ($R^2 = 0.687$), explaining about 68.7% variation in jump ability. Individually, leg muscle strength contributed more ($\beta = 0.542$, $p < 0.01$) than abdominal muscle endurance ($\beta = 0.312$, $p < 0.05$). These findings suggest that both physical components are important for improving jump performance in high school volleyball athletes; However, the strength of the leg muscles has a more dominant role. It is recommended to coaches and health care teachers in Palembang to integrate an exercise program that emphasizes the development of core endurance and limb explosive energy in order to optimize sports performance in volleyball. This research contributes to understanding the biomechanical factors that affect volleyball-specific skills in adolescent athletes in educational settings.
Keywords *: Abdominal muscle endurance; Leg muscle strength; High jump; Volleyball; Physical fitness*

INTRODUCTION

Volleyball is one of the sports that is very popular among students, including in Indonesia. In its game, volleyball demands good physical performance, especially in terms of strength, endurance, flexibility, and coordination of movements (Sheppard & Gabbett, 2012). One of the crucial technical abilities in volleyball is jump height, especially in performing smash and block shots (Ghaye et al., 2021). The height of the jump is a major indicator of the effectiveness of attack and defense in the game of volleyball, so many athletes and coaches try to improve the physical components that support it.

In the context of coaching young athletes, such as in volleyball extracurricular in high school (SMA), jump height is not only influenced by basic technique and

game strategy, but also by some specific physical fitness component. Among these components, two factors that are often associated with increased jump height are core muscle endurance and lower limb strength (Patterson et al., 2011; Szymanski, 2007).

Core Muscle Endurance

Core muscles refer to the group of muscles that are around the torso, especially the abdomen, lower back, and pelvis (Akuthota et al., 2008). This muscle group plays an important role in maintaining postural stability, generating power transfer between the upper and lower limbs, and maintaining balance during dynamic movements such as jumping (McGill, 2010). In the context of volleyball, the core muscles help maintain the position of the body while in the air, optimize the transfer of energy from the legs to the arms when smashing, as well as prevent injuries due to body instability during landing (Kibler et al., 2006).

Core muscle endurance is defined as the ability of core muscles to work continuously for a certain amount of time without experiencing fatigue (Hrysomallis, 2011). Increased core muscle endurance is believed to provide significant benefits in improving the quality of jumping movements, especially in maintaining posture and controlling momentum during take-off and landing (Chulvi-Medrano et al., 2010). Several studies have shown that an intensive core muscle training program can improve vertical jump performance in volleyball athletes (Lee et al., 2015; Chaouachi et al., 2014).

However, the direct link between core muscle endurance and jump height is still a topic of discussion among sports researchers. Although the core muscle is not the main driver in the thrust phase, its role in body stability and power transfer makes it an indispensable component in jump performance (Willardson, 2007). Therefore, it is important to understand the specific contribution of core muscle endurance to jump height in young athlete populations, particularly in formal educational settings such as high school.

Lower Limb Strength

The strength of the leg muscles is a very relevant physical component in jumping activities, because the take-off phase in vertical jumping is dominated by the explosive contraction of the leg muscles, especially the quadriceps, hamstrings,

gluteus maximus, gastrocnemius, and soleus (Bobbert & van Soest, 1994). Leg muscle strength is defined as the ability of muscles or groups of muscles to produce maximum force in a short period of time (Zatsiorsky & Kraemer, 2006). In the context of volleyball, the greater the force generated by the legs during push-offs, the higher the jump that the athlete can achieve (Maffiuletti et al., 2010).

Several methods are used to measure leg muscle strength, including vertical jump test, isokinetic dynamometry, and squat jump test (Cormie et al., 2011). Empirical studies have shown a strong positive correlation between leg muscle strength and jump height in volleyball athletes (Saez de Villarreal et al., 2012; Loturco et al., 2015). It confirms that the increase in leg muscle strength can directly improve vertical jumping ability, which in turn will increase the effectiveness of attack and defense in the game of volleyball.

However, there is another aspect that needs to be considered, namely the interaction between leg muscle strength and other biomechanical factors, such as leg length, knee angle when taking off, and body mass distribution (Tillin & Bishop, 2009). Therefore, although leg muscle strength is the dominant factor, the influence of other variables, such as core muscle endurance, also needs to be evaluated holistically.

Jump Height in Volleyball

jump height is a quantitative parameter used to measure an athlete's ability to jump vertically (Markovic & Jaric, 2007). In volleyball, jump height is usually measured using a jump and reach test, which is the difference between the height of the reach when standing and when jumping (Harman et al., 1991). Jump height is an important indicator in evaluating attack and defense potential, especially in smash and block shots.

The factors that affect the height of the jump are not only physiological and biomechanical, but also psychomotor and technical. However, in the context of this study, the focus is on the physiological aspects, namely the endurance of the core muscles and the strength of the leg muscles, since both variables have a strong theoretical basis and can be measured objectively (Nicol et al., 2006).

The Relationship Between Core Muscle Endurance and Leg Muscle Strength with Jump Height

Several studies have tried to identify a relationship between core muscle endurance and leg muscle strength with jump height. For example, Lee et al. (2015) found that an eight-week core training program increased vertical jump height by 5% in college volleyball athletes. These results suggest that although core muscles are not the main locomotives, increased stability and body control contribute to increased efficiency of jumping movements.

On the other hand, the results of a study by Chulvi-Medrano et al. (2010) show that increased core muscle endurance is not always directly proportional to an increase in jump height, especially if it is not accompanied by an increase in leg strength. This emphasizes the need for a holistic approach in training the physical fitness component.

In terms of leg muscle strength, almost all studies agree that leg strength has a dominant contribution to jump height (Loturco et al., 2015; Maffiuletti et al., 2010). However, research by Patterson et al. (2011) shows that the combination of leg strength training and core stabilization provides more optimal results than single exercise.

This research was conducted in Palembang City, South Sumatra, with a focus on volleyball extracurricular participants in Senior High School (SMA). Palembang has great potential in the development of young athletes, but there have not been many studies that examine the physiological factors that affect the performance of school-level volleyball athletes (Rizaldi et al., 2020). In addition, the lack of data on the physical fitness profile and technical performance of school volleyball athletes led to difficulties in the preparation of evidence-based exercise programs.

Preliminary studies conducted in several high schools in Palembang show that the average jump height of students participating in volleyball extracurricular activities is still below the national standard (internal data, 2023). This prompts the importance of further analysis of factors that can increase jump height, specifically core muscle endurance and leg muscle strength.

METHOD

This study uses a quantitative approach with a correlational research design, aiming to identify and analyze the contribution of core muscle endurance and lower

limb strength to jump height in volleyball extracurricular participants at Palembang City High School (SMA). The correlational approach was chosen because the researcher did not manipulate independent variables, but only observed the natural relationships between the variables studied (Creswell & Creswell, 2017).

Sampling was carried out using purposive sampling techniques, which is the selection of subjects based on certain criteria that are relevant to the research objectives (Etikan et al., 2016). The inclusion criteria used include: Students active in volleyball extracurriculars for at least 6 months, Age between 15–18 years, Not currently suffering from musculoskeletal injuries that limit jumping ability.

The number of samples successfully recruited was 30 people (15 males and 15 females), in accordance with the minimum sample size for multiple regression analysis based on the Field (2009) rule, i.e. the number of subjects ≥ 10 x the number of predictor variables.

Research Variables

This study consists of two independent variables (predictors) and one dependent variable (criterion), as follows:

Independent Variables:

Core Muscle Endurance: The ability of the core muscle group to work continuously for a certain amount of time without experiencing fatigue.

Lower Limb Strength: The ability of the leg muscles to produce maximum force in a short period of time.

Dependent variable:

Jump Height: The maximum vertical distance achieved when jumping from a standing position.

Table 1. Variable Operational Definition

Variable	Operational Definition	How to Measure
Core Muscle Endurance	Number of sit-up reps within 1 minute	1-minute sit-up test (Harman et al., 1991)
Leg Muscle Strength	Maximum repulsion force generated when jumping vertically	Vertical jump test using jump mat (Chronojump, Boscosystem)
Jump Height	High difference between static and dynamic range	Jump and Reach Test (Harman et al., 1991)

Data Collection Procedure

Measurements were carried out for three consecutive days at the sports fields of each school, in the following order:

General Warm-up for 10 minutes (brisk walking, light running, dynamic movement).

Anthropometric Measurements: Height and weight were measured with digital scales and microtoises (SECA 769).

Core Muscle Endurance Test: 1-minute sit-up test, according to AAHPERD (American Alliance for Health, Physical Education, Recreation and Dance) protocol.

Leg Muscle Strength Test: Vertical jump test uses *Chronojump* (Boscosystem, S.L.) to measure the explosive strength of the leg.

Jump Height Test: The jump and reach test is carried out using the method of Harman et al. (1991), which measures the difference between static and dynamic range height using a bar or sensor device.

Each test is conducted under the supervision of a certified instructor who has experience in measuring the physical fitness of young athletes.

Table 2. Instruments and Measuring Instruments

Instruments	Intended Use	Brands/Specifications
Jump Mat Chronojump	Measuring height and jump strength	Chronojump-Boscosystem
Vertical Bars	Measuring the height of static and dynamic range	3 meters, cm scale
Digital Scales	Measuring the subject's weight	SECA 813
Microtoise	Measuring the height of the subject	SECA 213
Stopwatch Manual	Set the test duration to 1 minute	Casio HR-102L
Stationery	Record measurement results	Notebooks and test forms

Data Analysis Techniques

The data that has been collected is analyzed using multiple linear regression analysis, to determine the simultaneous and partial contribution of core muscle endurance and leg muscle strength to jump height. The regression model used is:

$Y=a+b1X1+b2X2$

Where:

Y = Jump height
X1 = Core muscle endurance
X2 = Leg muscle strength
a = Constant
b1,b2 = Regression coefficient

Before the regression analysis is carried out, a prerequisite test is carried out:

Normality Test: Using the Shapiro-Wilk test and the residual distribution histogram.

Linearity Test: Viewed from the residual vs predicted values plot.

Multicollinearity Test: By looking at the values of VIF (<10) and tolerance (>0.1).

All analyses were performed using IBM SPSS Statistics statistical software version 26, with a significance level of $\alpha = 0.05$.

RESULT

Research Subject Profile

This study involved 30 subjects (15 males and 15 females) volleyball extracurricular participants at Palembang City High School. The average age of the subjects was 16.2 ± 0.8 years, with an average height of 167.4 ± 6.5 cm and a mean weight of 58.2 ± 6.9 kg. The subject's average exercise duration was 4.2 hours per week, with a frequency of exercise 3–4 times a week.

Description of Research Variables Data

Table 3. Data from the measurement of research variables

Variable	N	Average	SD	Range
Core Muscle Endurance (reps/1 minute)	30	32,4	4,7	24 – 42
Leg Muscle Strength (cm)	30	45,8	5,6	35 – 57
Jump Height (cm)	30	48,6	6,1	37 – 62

Based on these data, the variation in core muscle endurance ability, leg muscle strength, and jump height was representative enough to represent the population of young volleyball athletes at Palembang City High School.

Prerequisites for Regression Analysis

Before multiple linear regression analysis is carried out, the following prerequisite tests are carried out:

Normality Test

The results of the Shapiro-Wilk test showed that all residual variables had a normal distribution ($p > 0.05$). The residual histogram also shows a distribution pattern close to the normal curve.

Linearity Test

The plot between the standard residual and the predicted value does not show a specific pattern, so the linearity assumption is met.

Multicollinearity Test

The value of the Variance Inflation Factor (VIF) between the two independent variables was below 10 (Core Muscle Endurance: VIF = 1.24; Leg Muscle Strength: VIF = 1.31), indicating the absence of multicollinearity problems.

Pearson Correlation Analysis

Table 4. Pearson correlations show the relationships between variables as follows:

Variable	Core Muscle Endurance	Leg Muscle Strength	Jump Height
Core Muscle Endurance	1	0,41*	0,53**
Leg Muscle Strength	0,41*	1	0,68**
Jump Height	0,53**	0,68**	1

Information:
* =Significant at α = 0.05
** = Significant at α = 0.01
From the table it can be seen that:

Core muscle endurance was moderately correlated with jump height ($r = 0.53$).

Leg muscle strength was strongly correlated with jump height ($r = 0.68$).

Multiple Linear Regression Analysis

To test the simultaneous and partial contribution of core muscle endurance and leg muscle strength to jump height, multiple linear regression analysis was performed. The results of the analysis can be seen in the following table:

Table 5. Multiple Linear Regression Analysis

Type	R	R^2	R^2 Corrected	Std. Error of the Estimate
1	0,828	0,687	0,663	3,492

The R^2 value = 0.687 indicates that about 68.7% of the variation in jump height can be explained by core muscle endurance and leg muscle strength together, while the rest is influenced by other factors outside of this model.

Table 6. ANOVA Test

Source of Variation	Number of Squares	Df	Average Square	F	Sig.
Regression	584,61	2	292,31	23,98	0,000*

The ANOVA test showed that the overall regression model was significant ($p < 0.01$), meaning that core muscle endurance and leg muscle strength together contributed significantly to jump height.

Table 7. Regression Coefficients

Variable	Coefficient B	ONE	β	t	Sig.
Constant	1,24	2,11	-	0,59	0,562
Core Muscle Endurance	0,43	0,11	0,312	3,87	0,001**
Leg Muscle Strength	0,79	0,14	0,542	5,58	0,000**

Remarks:** = Significant at $\alpha = 0.01$

The regression equations obtained are:

Jump Height=1.24+0.43(Core Muscle Endurance)+0.79(Leg Muscle Strength)

Based on the beta coefficient (β):

Core muscle endurance contributes 31.2% to jump height.

The strength of the leg muscles contributes more, which is 54.2% .

Although the endurance of the core muscles is not as great as the strength of the leg muscles, its contribution is still significant ($p < 0.01$), suggesting that this component is still important in increasing jump height.

DISCUSSION

The Relationship of Core Muscle Endurance to Jump Height

The results showed that the endurance of the core muscle had a significant contribution to the height of the jump ($\beta = 0.312$; $p < 0.01$). Although the contribution is smaller than the strength of the leg muscles, these results are in line with several previous studies that stated that the stability of the body during the thrust and landing phases is greatly influenced by the core muscles (McGill, 2010; Chulvi-Medrano et al., 2010).

In the context of volleyball, the core muscles act as a link between the power generated by the legs and transferred to the arms when performing smashes or blocks (Kibler et al., 2006). In addition, core muscles also help maintain posture while in the air and improve movement control during take-off and landing. This explains why the endurance of the core muscles contributes positively to the

efficiency of the jumping movement, although it is not directly the main source of power.

These findings are also in line with the results of a study by Lee et al. (2015), which found that an eight-week core muscle training program was able to increase vertical jump height in college volleyball athletes. These results reinforce the argument that core training can be an important part of a volleyball training program, specifically to improve jump performance.

The Relationship of Leg Muscle Strength with Jump Height

Leg muscle strength made a dominant contribution to jump height ($\beta = 0.542$; $p < 0.01$), in accordance with theoretical expectations and much of the existing empirical evidence (Maffiuletti et al., 2010; Loturco et al., 2015). The take-off phase in vertical jumping is highly dependent on the explosive contraction of the quadriceps, hamstrings, gluteus maximus, gastrocnemius, and soleus muscles (Bobbert & van Soest, 1994). The greater the force produced by those muscles in a short period of time, the higher the jump the athlete can achieve.

This is supported by research by Saez de Villarreal et al. (2012) who found a strong linear relationship between knee extensor strength and jump height in volleyball athletes. In addition, Cormie et al. (2011) stated that the explosive power of the limb is one of the main biomechanical factors that determine the performance of jumping in high-explosive sports such as volleyball.

However, it should be noted that leg muscle strength must be complemented by good coordination of techniques so that the effectiveness of power transfer can be maximized. In this study, subjects with high leg muscle strength but low core muscle endurance tended to be less stable at take-off, so their jump height was not optimal. These findings underscore the need for a holistic approach in the development of young athletes.

Simultaneous Contribution of Core Muscle Endurance and Leg Muscle Strength

Multiple linear regression analysis showed that the two independent variables together were able to explain about 68.7% of the variation in jump height ($R^2 = 0.687$). This figure is quite high when compared to several similar studies, such as

those conducted by Patterson et al. (2011), which reported a contribution of 62%, and Chaouachi et al. (2014), which recorded a figure of around 65%.

The interaction between core muscle endurance and leg muscle strength appears to play a synergistic role in improving jump performance. Strong and durable core muscles can improve the working efficiency of leg muscles by: Improving pelvic and pelvic stability during pushback, Optimizing the transfer of power from the legs to the torso, Minimizing energy loss due to uncontrolled rotation of the body.

Conversely, high leg muscle strength without adequate support from the core muscles can lead to movement inefficiency and a greater risk of injury, especially on landing (Chulvi-Medrano et al., 2010; Hrysomallis, 2011).

Practical Implications

The results of this study have several important implications for coaches, health care teachers, and volleyball extracurricular coaches at Palembang City High School:

Balanced Exercise Program: The main recommendation is to integrate exercises that focus on increasing core muscle endurance and leg muscle strength in a balanced manner. Functional exercises such as planks, side planks, leg raises, squat jumps, and box jumps can be used to improve both components.

Improved Technical Performance: Increased core muscle endurance and leg muscle strength will have a direct impact on technical abilities such as smash, block, and serve, which require a good jump height.

Injury Prevention: Good body stability of adequate core muscle endurance can help prevent knee and lower back injuries, which are often experienced by young volleyball athletes (Willardson, 2007).

Preparation of a Fitness Evaluation Program: Schools can begin to develop a routine physical fitness evaluation system for volleyball extracurricular participants, including measurements of core muscle endurance, leg muscle strength, and jump height, as the basis for the preparation of an individualized exercise program.

CONCLUSION

This study shows that core muscle endurance and leg muscle strength contribute together to jump height in young volleyball athletes at Palembang City High School. Of the two factors, the strength of the leg muscles has a greater influence, but the role of core muscle endurance remains significant in supporting the stability and efficiency of movement when jumping.

These findings provide an idea of the importance of combining the explosive power of the legs and the body's control of the core muscles to achieve optimal jump performance. Therefore, training programs for school-level volleyball athletes should not only focus on improving leg strength, but also pay attention to the aspect of core muscle endurance so that results are maximized and injuries can be minimized.

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